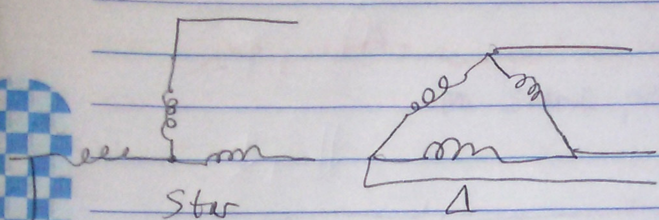
Chapter 5

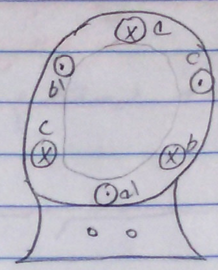
Synchronous generators

$$N = N_s = \frac{120 F}{P}$$

* Stator

هو نفس الـ Stator الخاص بـ 3ϕ Induction





Star	Δ
$V_L = \sqrt{3} V_{ph}$	$V_L = V_{ph}$
$I_{ph} = I_L$	$I_L = \sqrt{3} I_L$

$P = 3 V_{ph} I_{ph} \cos\theta$

$P = \sqrt{3} V_L I_L \cos\theta$

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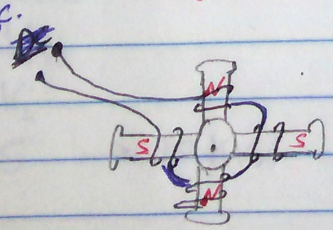
* rotor

① salient pole ((selented))

الروتر ذو الأقطاب البارزة
((إسطوانة))



في المحطات المائية

$P \geq 4$

مسؤول عن توليد الفيض

rotor → Field

Stator → Armature

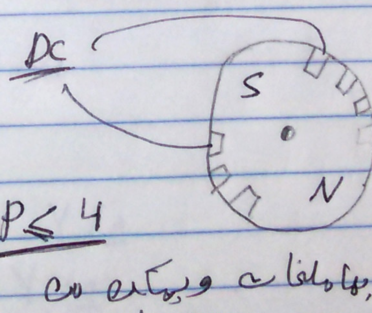
يتم توصيل الجهد من خلال 2 Brushes

الآلة لها 8 أطراف

2 D.C → rotor

6 AC → Stator

② Non salient pole (([illegible]))



$P \leq 4$

مجاري بها ملفات ويمكن من خلالها تحديد عدد الأقطاب

في المحطات البخارية

$$f = \frac{N_s \, P}{120}$$

$f = 50 \text{ Hz}$

المحطات المائية

سرعة الدوران قليلة ← لابد من زيادة عدد الأقطاب

وهذا التعديل يسهل مع Salient poles

المحطات البخارية أو الحرارية

سرعة الدوران كبيرة ← لابد من عدد أقطاب صغير

لذلك يستخدم un Salient poles

فكرة العمل

نتيجة دورانه rotor مع خطوط الفيض يحدث قطع لخطوط stator

$$E_a = 4.44 \, T_{Ph} \, \phi F$$

- T_{Ph}: عدد لفات لكل ϕ — Number turns per phase
- ϕ: Flux/pole
- F: Frequency $= \frac{P N_s}{120}$

مواصفات الآلة

$V_{D.C}$

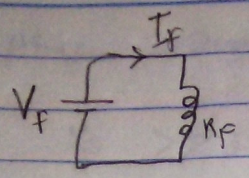
V_{Ph}

V_L

$S \rightarrow 10 \text{ KVA}$, $380V/220$ (Line / Line) Y/Δ

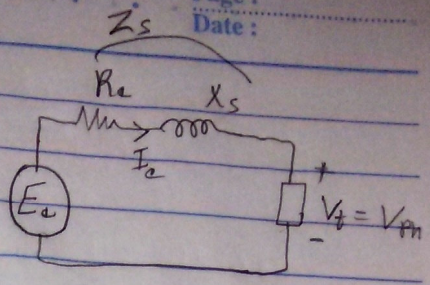
I_L / I_{Line} Y/Δ

$$S = I_L V_L \sqrt{3}$$



Rotor

$E_a = 4.44 \; T_{ph} \phi F$



Stator

$R_a \rightarrow$ Armature resistance / phase

$X_s \rightarrow$ Armature reactance / phase

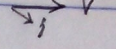
$$Z_s = R_a + jX_s$$

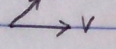
$$V_t = E_a - I_a(R_a + jX_s)$$

$$E_a = V_t + I_a(R_a + jX_s)$$

$$\bar{E}_a = E \angle \delta$$

Loads

Lag P.F 

Lead P.F 

Unity P.F 

$\delta \rightarrow$ power angle , load angle , Torque angle

هو الزاوية بين E_a و V_t في حالة الحمل

هو الزاوية بين E_a و V_{ph} في حالة الحمل

$$P = 3 V_t I_a \cos\theta$$

$$I_a = \frac{P}{3 V_t \cos\theta} \angle \pm \cos^{-1} P.F$$

(lead) / (lag)

$$V_t = |V_t| \angle 0^\circ$$

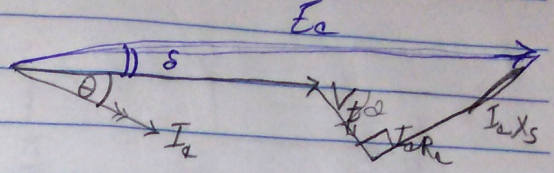
$$I_a = \frac{S}{3 V_t} \angle \pm \cos^{-1} P.F$$

(lead) / (lag)

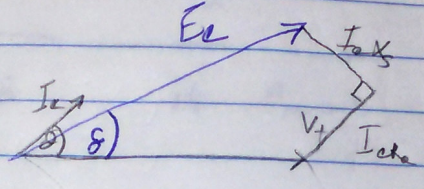
Page :
Date :

Phasor Diagram For lag P.F

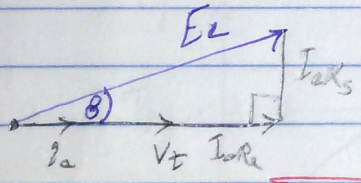
$X_s >> R$

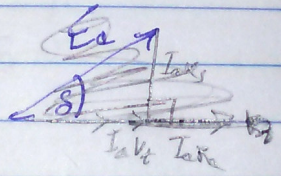


Const P.F

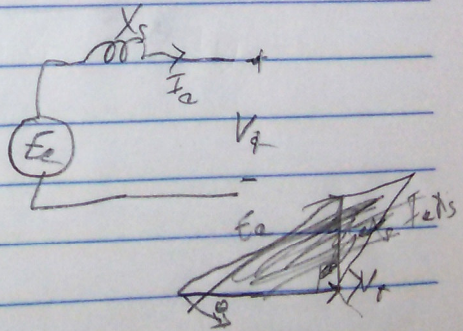


Unity P.f





Power relation



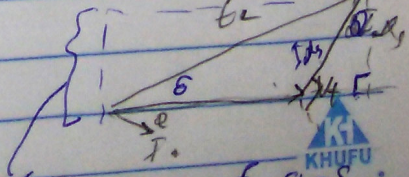
Let $R_a = 0$

$$E_a = V_t + I_a(jX_s)$$

$$I_a X_s \cos\theta = E_a \sin\delta$$

$$3V_t I_a X_s \cos\theta = 3V_t E_a \sin\delta$$

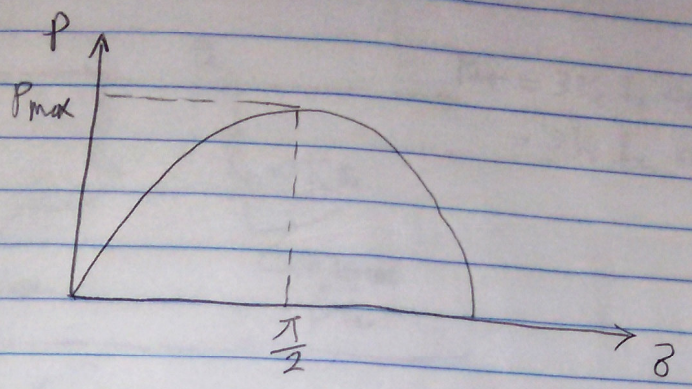
$$\boxed{P = 3V_t I_a \cos\theta = \frac{3V_t E_a}{X_s} \sin\delta}$$



$I_a X_s \cos\theta = E_a \sin\delta$

$P_{max} = \frac{3 E_a V_t}{X_s}$ at $\delta = 90^\circ$

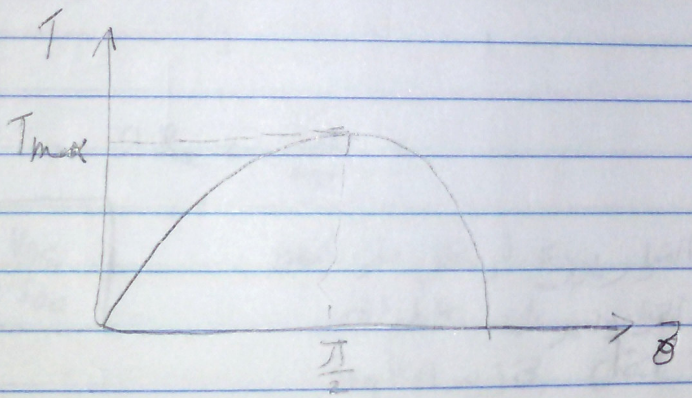
$\delta \rightarrow 0^\circ : 90^\circ$



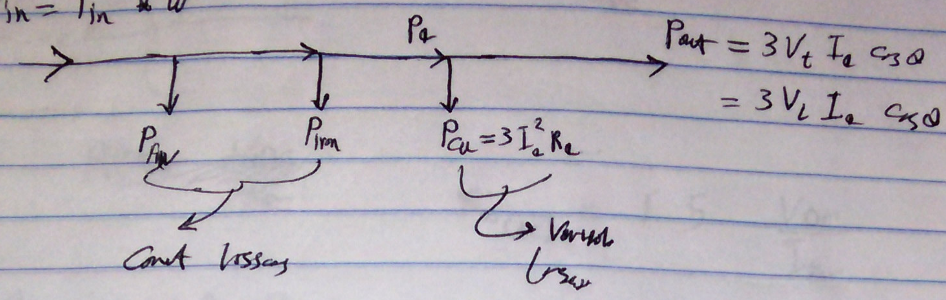
$P_e = \frac{3 V_t E_a}{X_s} \sin\delta$ at $R_a = 0$

$T_e = \frac{P_e}{\omega} = \frac{3 V_t E_a}{\omega X_s} \sin\delta$ $\omega = \frac{2\pi N_s}{60}$

$T_e = T_{max} \sin\delta$



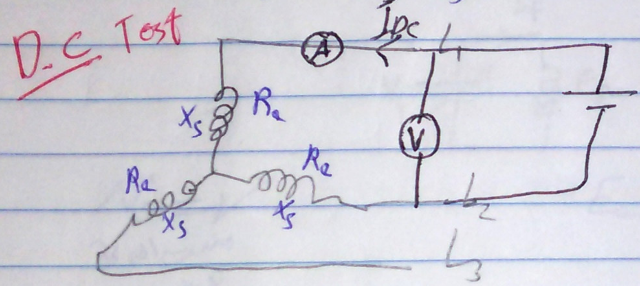
Power Flow of synchrous Generator:



Parameter R_a, X_s

Measurment of syncronous Generator parameters: (R_a, X_s)

D.C Test



$X_s = 0$ $\qquad 2R_a = \frac{V_{DC}}{I_{DC}}$

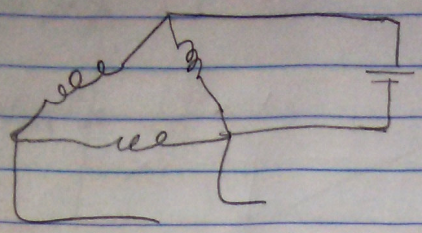
$$R_{a_{DC}} = \frac{V_{DC}}{2 I_{DC}}$$

في حالة DC التيار بيوزع بإنتظام على السلك
لو AC التيار بيمر على الأطراف
المساحة تقل وتزيد المقاومة
وتزداد كلما زاد التردد

$$R_a = (1.15 \rightarrow 1.25)\ (R_a)_{dc}$$

هفترض دايمًا إنها

$$R_{a(AC)} = 1.2 * R_{a(d.c)}$$



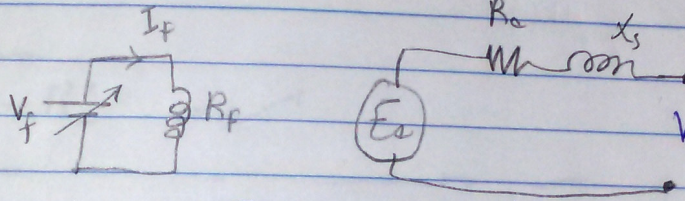
$R_f = \frac{V_{DC}}{I_{DC}}$ ~~$= \frac{2}{3} R_a$~~

~~$R_a = \frac{V_{DC}}{I_{DC}}$~~

$R_{a(dc)} = 1.5 \frac{V_{DC}}{I_{DC}}$

$R_{a(ac)} = 1.2 \; R_{(dc)}$

2) Open Circuit Test



$N_s = V$

$E_a = 4.44 \; T_{ph} \phi f$

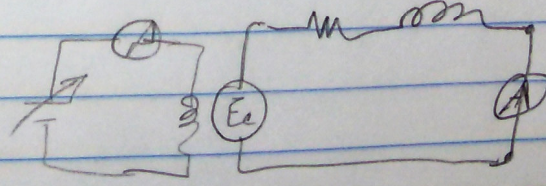
$E_a \propto \phi$

I_f	0	0.1	———	I_{fM}
$V_{o.c}$	✓	✓	———	✓

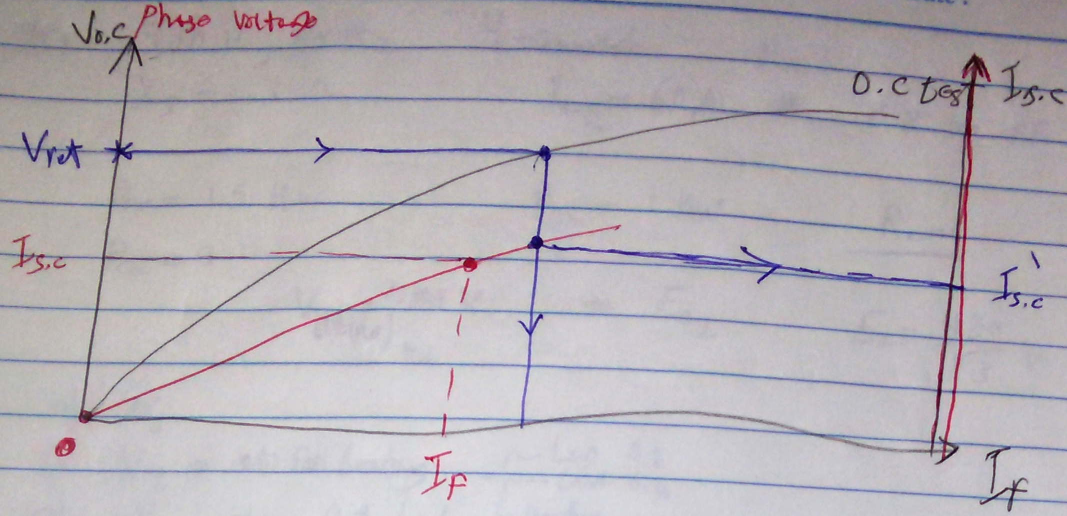
3) Short Circuit test

N_s =

$X_s \rightarrow X_{leakage}$
$\quad \hookrightarrow X_{armature\ reaction}$



IF	0	✓
$I_{s.c}$	0	✓ I_{FL}



$$Z_s = \frac{V_{rat}}{I'_{s.c}} = \checkmark \ \Omega$$

$$X_s = \sqrt{Z_s^2 - R_a^2} = \checkmark$$

شروط توصيل ~~...~~ مولدين على التوازي في الشبكة

1) نفس التردد
2) نفس الجهد
3) نفس Phase Sequence
~~4) لا يوجد بين كل 2 phase shift~~
4) Phase shift = 0

Page :
Date :

ex: 480 V, 50 Hz Y-Connected P = 6
$X_s = 1\ \Omega$ $I_{a_{FL}} = 60$ A at 0.8 lag PF

$P_{fw} = 1.5$ kW $P_{irn} = 1$ kW $R_a = 0$
$P_{cu} = 0$

$V_{t(line)_{n.l}} = 480$ V $= E_{a_L}$ $E_a = \frac{480}{\sqrt{3}}$ V

a) N_s
b) V_t at Full Loading — Lag 0.8, Lead 0.8, unity
c) η at 0.8 Lead pf
d) T_{in}

$$N_s = \frac{120F}{P} = \frac{120 * 50}{6} = 1000 \text{ rpm}$$

Lag

$$V_t = E_a - I_a(X_s j)$$

$$|V_t|\angle 0^\circ = \frac{480}{\sqrt{3}}\angle \delta - 60\angle -\cos^{-1}0.8 * 1\angle 90 \rightarrow (1)$$

$$P_a = \frac{3V_t E_a}{X_s}\sin\delta = 3V_t I_a \cos\theta$$

$$\delta = \sin^{-1}[I_a X_s \cos\theta] = \checkmark \quad \text{in } (1)$$

$$|V_t| = \checkmark$$

Lead

$$|V_t|\angle 0^\circ = \frac{480}{\sqrt{3}}\angle \delta - 60\angle +\cos^{-1}0.8 * 1\angle 90$$

$\delta =$ نفس اللي فوق

Unity $\delta \rightarrow PF = 1$

$$|V_t|\angle 0^\circ = \frac{480}{\sqrt{3}}\angle \delta - 60\angle 0^\circ * 1\angle 90$$

Page :
Date :

$$\eta = \frac{P_{out}}{P_{in}} = \frac{3 V_t I_a \cos\theta}{P_{out} + P_{cu} + P_{in}} = \checkmark$$

$$T_{in} = \frac{P_{in}}{\omega} = \frac{P_{cu} + P_{cu} + P_{in}}{\left(\frac{2\pi N_s}{60}\right)} = \checkmark$$

Voltage Regulation
- 0.8 Lag
- 0.8 Lead
- unity

$$V.R = \frac{V_{nL} - V_{FL}}{V_{FL}} * 100$$

$$= \frac{E - V_t}{V_t} * 100 = \checkmark$$